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THE SHIFTING OF CLIMATIC ZONES AS ILLUSTRATED IN MEXICO*

BY ELLSWORTH HUNTINGTON

Let us turn now to a type of evidence which has not yet been discussed in print so far as I am aware. Hitherto practically all conclusions as to changes of climate have been based upon the phenomena of dry countries, and what has been said above in respect to Mexico is no exception. Let us now turn to moist regions. When I mentioned to Mr. Urbinas of the Geological Institute of Mexico my intention to visit some of the ruins in the extreme south of the country, he remarked that I would probably find them very interesting because they are located in places so damp and so densely forested that no one can live there now. Unfortunately he has not put his observations into print, but they deserve to be recorded. My own experience strongly confirmed the opinion of Mr. Urbinas. In the center of Yucatan at a distance of about a hundred miles each from the Gulf of Mexico on the west, the northern shore of Yucatan on the north and the Caribbean Sea on the east lies the narrow lake of Chichankanab. In this region, as I have explained in another article,† the tropical jungle of northern Yucatan gives place to genuine tropical forest. Instead of bushes and small trees which rarely exceed a height of twenty-five feet, the predominant vegetation is large trees fifty or sixty feet high. The air is always moist and warm so that whenever an old tree dies new vegetation sprouts with the utmost rapidity. The majority of the trees are hardwood species. Hence it is difficult to make clearings. If the trees are girdled in order to kill them off and allow of their being removed by burning, new vegetation grows up rank and lush before the old trees are dry enough to burn. The new vegetation is too moist to be burned, and so the natives are forced to cut once more. Even such a double cutting may not avail if rains are frequent, for new plants will sprout under such circumstances before the old ones are dry enough to burn. This makes the process of clearing the tropical forest extremely difficult. To this are added all the manifold disadvantages of innumerable malarial fevers, and of a damp, enervating warmth which tends continually to prevent instead of stimulate effort. In a word the difficulty of making clearings and carrying on cultivation in the tropical forest is so great that in the true forest as distinguished from the jungle no agricultural community appears at present to have succeeded in subduing more than a few merely temporary or exceptional areas.

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* Concluded from the January *Bull.*, pp. 1–12.

† *Bull.*, Vol. 44, 1912, pp. 807–809.

The people living in the forest at the southern end of Lake Chichankanab at the present time are confined to a few widely scattered and barbarous Indians and a temporary population of *chicleros,* or men who come for a few months to gather the sap of the zapote tree for the purpose of converting it into chewing gum. Nevertheless, abundant ruins exist in this region. I discovered one of these a mile northeast of Esmeralda, the central camp of a chewing-gum concession which covers several thousand square miles but boasts of nothing more than four or five palm-thatched sheds at its headquarters. At the ruins I found abundant piles of stones indicating structures of various shapes and sizes from twenty feet square up to over a hundred in length by more than half as much in width. In one place some small pyramids appear to have been sacrificial, or at least ceremonial structures. Others were probably temples, and presumably the smaller ones were houses. In many cases the stones forming the outer portions of the walls were neatly smoothed and the corners of the buildings were carefully rounded, a task of no mean proportions for people who had no iron tools. The style of architecture is the same as that of the magnificent ruins of the northern, or jungle portion of Yucatan, steep arches with a capstone instead of a keystone, and with a massive filling of masonry between the consecutive arches. Evidently the people who built the magnificent temples of Kabah, Sayi, Uxmal, and Chichenitza spread their sway much beyond the present limits of civilized habitation, and penetrated into regions which now are covered with a thick tropical forest.

The most remarkable feature of the ruins is the evidence which they furnish of a comparatively dense population. At the Esmeralda site my guide took me along a winding path made by gum-gatherers on their way to find zapote trees. It was a mere trail, where the guide had to stop every few steps to hew down fresh palm saplings, or fallen trunks, or to cut long lianas hanging down from the trees. It was not made with any reference to ruins, and the undergrowth was so thick that we could almost never see more than twenty-five or at most fifty feet into the forest. Nevertheless, in the distance of a mile we counted over twenty-five heaps of ruins. If the forest were cleared off, undoubtedly one would see traces of many times as large a number of structures, hundreds in all probability. Moreover, this is not the only place where evidences of a dense ancient population are found in the deep forest. My guide was evidently surprised that I should be so interested in mere mounds of stone, but he volunteered some valuable information. In the hunting trips which occupy a large portion of his time during the season when chewing-gum is not being gathered, he has traversed the surrounding forest for fifteen or twenty miles in almost every direction, and "everywhere," as he put it, has come across numerous mounds indicating ancient houses. Similar phenomena are found in certain other parts of Mexico and Central America. For instance, Palenque, in the Mexican state of Chiapas west of Yucatan, is noted as the site of some of the most magnificent ruins in America, ruins which are not only massive, but are beautifully and elaborately carved. They are located in what is described as the thickest kind of tropical forest. The size of the ruins and their large amount of sculpture indicate that the surrounding city must have been long inhabited by a dense population. Moreover, the people must have been highly industrious or they never could have accomplished such great results, especially when they had no iron tools to aid them, nothing but stone so far as has yet been determined.

In order to explain the occurrence of such evidences of high civilization in so unfavorable an environment one of two assumptions appears to be necessary; either the ancient people of America were far more capable than any tropical people of to-day and even than any European race which has yet learned to dwell in the tropics, or else the climate was different from that of the present, so that the tropical forest was replaced by tropical jungle. If the ancient inhabitants actually mastered the forest, they accomplished a task of extreme difficulty. Without iron tools they could scarcely clear large areas of hardwood trees, and if they merely girdled them, the difficulty of getting rid of the exuberant vegetation which would at once spring up before the girdled trees were ready to burn, would, as we have seen, be very great. Perhaps the old Yucatecos succeeded in this task, but if they did they accomplished something not now achieved by any modern tropical people, even though the modern races have the assistance of good steel tools. Moreover, they accomplished something which it is at least doubtful whether the races of Europe could at present accomplish if they were limited merely to stone implements.

The assumption of such wonderful ability on the part of the ancient Yucatecos seems unnecessary in view of the fact that there is another equally good hypothesis which has much more support. We have already seen that various lines of evidence indicate that changes of climate in Mexico have taken place in the same way as farther north. The general effect of climatic changes seems to be to shift the peculiarities of one latitude into another latitude. Inasmuch as the chief change during the past 2,000 or 3,000 years, in the sub-tropical regions where the subject has been chiefly studied, appears to have been in the direction of aridity, the general shifting seems to have carried the conditions of more southerly regions into those farther north. This would seem to mean that at the beginning of the Christian era or earlier the zone of westerly storms, during the winter, at least, lay farther south than to-day and thereby prolonged the rainy season in the present sub-tropical zone, causing the period of precipitation to begin earlier and last longer than now, and thus making the country less arid than at present. The natural corollary of this would be that the sub-tropical zone of aridity was displaced southward. This might have no appreciable effect upon the sub-equatorial summer rains, but it would prevent rainfall during the winter, and would thus prolong the dry season. This would be to the detriment of forest trees which, so the botanists say, cannot endure any long period of aridity during the growing season. Such a change would cause a diminution of vegetation along the northern edge of the tropical zone of jungle and would cause jungle to take the place of genuine, dense forests still farther south. In Yucatan and other parts of southern Mexico or Central America the transition from jungle to forest is often quite sudden. For instance, in the region of Yucatan, it occurs within a distance of thirty or forty miles. If the line of transition were shoved southward fifty or a hundred miles it would cause jungle to prevail where the ruins are now found.

Such a change as has just been described would not merely explain the location of great ruins in regions now too densely forested to be habitable. It would also at least partially relieve us of the necessity of assuming that the ancient Yucatecos possessed a degree of energy and ability quite out of harmony with anything which now exists in regions so warm and debilitating as Yucatan. This would work through both direct and indirect stimulation. The indirect stimulation can be easily explained. Not only would the area of jungle be increased at the expense of the forests, thus enlarging the habitable area, but the regions where jungle now prevails might also become drier, and thus agriculture might become somewhat more difficult than at present in places where it is now easy. If the people were at all energetic this would to a certain extent act as a stimulant. In order to get a living the inhabitants would be obliged to work harder and take more forethought than is now the case, although they would still find no great difficulty provided they worked with energy. Accordingly, energy, forethought and the qualities which advance civilization would be at a higher premium than now, and the portion of the populace which did not possess these qualities would tend to be eliminated.

The direct effects of a change of climate upon the Yucatecans cannot so easily be estimated. Before attempting to discuss them it will be well to examine more closely the possible mechanism of a shifting of the great climatic zones. This can best be understood by considering first what happens during our ordinary winters. Most of the rainfall of the United States is derived from cyclonic storms, that is from great areas of low pressure and in-blowing winds which may have a diameter of 500 or 1,000 miles, and which sweep across the country with a general easterly trend in obedience to the prevailing direction of the winds in temperate latitudes. The courses of these storms, so far as they are understood, are determined by the differences in pressure between the various more or less permanent areas of high or low barometer which center over oceans and lands in various latitudes and with varying degrees of intensity at different seasons. In general, storms move out from, or around areas of high pressure and are drawn toward those of low pressure. Anything which changes the location or intensity of the major pressure areas changes the course and intensity of storms. The North Atlantic Ocean, by reason of the high degree to which it is warmed by the Gulf Stream, is a most important area of permanent low pressure. To this is thought to be due in large measure the fact that the northern United States and Canada on the west and northwestern Europe on the east, together with the Atlantic Ocean between them, are the most stormy regions of the globe. In summer, when the continents become warm, and therefore are characterized by low pressure, the North Atlantic low area decreases in importance. The difference in pressure between land and sea is relatively slight, and the storms are correspondingly mild. They move more nearly from west to east than in winter, although, of course, with distinct curves, and their tracks, as a rule, are located well up toward the north. In winter, on the contrary, the continents cool off and become areas of pronounced high pressure, while the oceans are areas of low pressure.

At this time the difference in pressure between North America and the North Atlantic reaches a maximum, the barometric gradients are steep, and storms are correspondingly fierce. The courses of the storms under such conditions are more curved than in summer, and lie farther south. The center of the continent becomes so cold that an extensive area of permanent high pressure is formed. From this the winds blow outward. Thus the storms which would otherwise move more or less directly east from the Pacific to the Atlantic seem in many cases to be forced far to the south. Starting in California a storm may swing southeast into Arizona and Texas, and then move east and finally come up the Atlantic coast and swing off toward the low center of the North Atlantic. In its wake such a storm may send the thermometer down to twenty degrees Fahrenheit in southern Arizona and kill the peach blossoms which have opened too early. Farther south or east it may produce a "norther" with a temperature of 50° in Yucatan and kill the orange trees in Florida. The number of storms which follow such southerly courses varies greatly from year to year. Upon these variations the character of the winter largely depends. In 1911-12, for example, the northern parts of the United States had few storms and slight snowfall as a general rule during the middle of the winter, although this was compensated for toward spring. Farther south, however, storms which had gone far equatorward brought to Texas and northern Mexico more than the usual amount of rain, while Yucatan also had a comparative abundance of showers and of "northers." The conditions were by no means remarkable, but they serve to illustrate the fact that the variation in the tracks of the storms brings with it important results in the way of variations in rainfall and temperature. The winter of 1911-12 was characterized by a relatively pronounced and long continuing area of high pressure over the central part of North America, and therefore the storms for a season went far to the south.

If periods of more than a single year are examined, it appears that the general course of the storm track varies. Dunwoody investigated the storm tracks of the earth some years ago, and, so far as data were available, made a map* showing the average number of storm centers passing over each five degrees square of the northern hemisphere during the period of ten years from 1878 to 1887. His map shows that the number of storms is greatest in the region of the Great Lakes of North America, and is large throughout all of the northern United States, southern Canada, northwestern Europe, and Japan. In order to test this map Professor C. J. Kullmer of the University of Syracuse has reconstructed the portion for the United States for a period twenty-one years later. Unfortunately Kullmer's map has not yet been published, but he has kindly permitted me to use it in manuscript. It shows that in the later period the center of maximum storm frequency had moved a little to the south and west from its previous location. In other words, the average storm in 1883 or thereabouts followed a course slightly farther toward the south and west than did the average storm in the period centering around 1904. To put the matter in another way, between the times of the two maps the zone of prevailing westerly storms moved very slightly equatorward from its earlier position. I would not be understood as magnifying the slight differences between the two maps. Doubtless conditions may soon once more become the same as they were during the period covered by Dunwoody's map, and there is no reason to suppose that any great or permanent change has taken place. The important point, however, is that here we have direct evidence that the climatic zones of the world are at the present day subject to minor shiftings back and forth, and that these shiftings on a small scale produce results like those which our assumed larger and more prolonged shiftings appear to have produced upon a really important scale. Meteorologists almost universally recognize the fact of such minor shiftings, and it is valuable to have the matter definitely recorded in two maps which can readily be compared. To sum up the matter briefly, in the irregular little cycles which cause the climate, or weather, of one year to differ from that of the next, the course of the storm tracks varies, moist periods in sub-tropical regions being characterized by southerly tracks. In longer periods, such as the 21 years between Dunwoody's and Kullmer's maps, the same sort of variation is seen on a larger scale. Therefore it seems reasonable to suppose that in still longer and more important periods the same thing occurs with a correspondingly increased intensity.

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* Cf. Pls. 28 and 29, Atlas of Meteorology (Bartholomew's Physical Atlas, Vol. III).

In discussing the changes of climate which appear to have taken place in Asia, I have elsewhere stated that they appear to be of the same nature as those of the glacial period, the only difference being one of degree, not kind. In the western hemisphere the evidence points to the same conclusion. Hence it will be of value to consider some of the latest results of researches upon the conditions of glaciation in polar regions at the present time. To meteorologists and glaciologists one of the surprising results of recent explorations of Greenland and the Antarctic continent has been the discovery that these ice-capped areas are regions of high rather than of low pressure. Previously it had been supposed that the general low pressure, which appears to become more and more pronounced as one goes poleward, prevails over all lands where continental ice-sheets now exist. It was thought that only in this way could sufficient precipitation be obtained to support the great ice-fields and to supply ice for the thousand of bergs and floes which wreck our ships. As soon as explorers began to study the winds of ice-capped regions with any care, however, they discovered that the prevailing movement of the air is strongly outward. At times it may be reversed, but not for long. This means, of course, that high barometric pressure prevails in the interior and is busily forcing the air outward except at times when some general disturbance upsets the normal conditions. This is what would naturally be expected, since vast areas of snow are bound to be extremely cold and hence are likely to induce high barometric pressure. Hitherto, however, it has generally been supposed that such almost continuous high pressure could not characterize such regions because there would be no way of obtaining precipitation. It remained for Professor Wm. H. Hobbs in his valuable book on glaciers to focus attention upon this point. He has attempted to explain the matter by an ingenious hypothesis to the effect that under the peculiar conditions of glaciation and of the newly discovered inversion of atmospheric temperature at high levels, fine crystals of snow can be deposited even when the barometer is high and the air clear. Whether his theory is sound or not I do not attempt to determine, but it has much to be said in its favor. Its chief value, however, lies in its emphasis of the fact that regions of continental glaciation appear to be areas of high pressure. This being so, an increase in the area of continental glaciation would apparently be conditional upon an increase in the area of permanent high pressure. At the height of a glacial period high pressure, according to this theory, would prevail throughout the year over a large part of the northern half of North America. If other conditions remained so far as possible the same as at present, the barometric gradients from the great glaciated areas of high pressure to the low areas of the oceans and of equatorial regions would be far steeper than now. Hence the winds would acquire great strength. Storms would doubtless be even more numerous than now, and they would follow more southerly courses. Forced far to the south by the great continental high areas both in North America and in northwestern Europe they would swing down into southern Mexico or the Sahara Desert, as the case might be, and the climates of those southerly regions would partake of the unstable character which today is so characteristic of the parts of North America and Europe where the world's most progressive races dwell.

If we are right in supposing that the climatic changes of which we seem to have found evidence during historic times are of the same nature as those of the glacial period, we can readily see how in the days of Yucatan's glory the storminess of the United States may to a certain extent have been shifted to the south. Under such conditions winter storms may have been more frequent and severe than is now the case; the winds may have blown more forcibly; and the minimum temperature may have fallen as low as freezing instead of only to 50°. The winter rainfall may also have been slightly larger than now in the drier parts of Yucatan, although not necessarily in the regions farther south where now the sub-equatorial forest prevails. There, in fact, as we have already seen, the chances are that conditions would be much drier than now, for the slight precipitation due to the southern edge of cyclonic westerly storms would by no means compensate for the pushing southward of the present type of winter rain. In summer, on the other hand, if a permanent and extensive high pressure area was located in the northeast of the continent, or extended out from Greenland, the sub-equatorial zone of rains may not have been able to shift so far to the north as at present. Hence less rain may have fallen, and the country may have been distinctly drier than at present, although the northern part of the country may have had a few winter showers which it does not now enjoy.

At best the theory here presented is only an approximation to the truth; at worst it is a suggestion which may lead to the evolution of a more satisfactory hypothesis. Already the careful reader has probably detected a possible inconsistency in the conclusions stated above. As here presented the theory of the shifting of climatic zones assumes that a given change of climate will produce opposite effects on the northern border of the sub-tropical zone of aridity as compared with the southern border. If this is so, it might be expected that the fluctuations of the lakes around Mexico City would indicate conditions exactly the reverse of those recorded in the growth of the sequoias in California. This, however, is only partially the case. The importance of this apparent discrepancy cannot yet be determined. It may mean merely that although the major climatic variations occur in accordance with our theory, minor fluctuations occur independently on the northern and southern sides of the sub-tropical zone. It may mean also that the interpretation here presented is erroneous. Possibly an increase in the high pressure area at the north and a consequent increase in the velocity of the winds would not only cause the cyclonic storms of the temperate zone to move farther south in winter than is now the case, but would also bring the equatorial rains farther north in summer. If this is so some of our conclusions as to Yucatan must be modified. The jungle of the past instead of having been more extensive than that of the present would have been less extensive, and the forest greater. Therefore the difficulties of the ancient Yucatecos would have been increased. In that case it becomes more difficult than ever to explain how a tropical people was able to accomplish such wonderful results. Yet it is possible that the summer rain might migrate farther north than at present and yet not cause the forests to increase. If the rainy period were shorter than at present because of the pushing southward of the climatic zones, the forests would suffer even though the summer rains did migrate farther north.

So far as the possible stimulus of greater climatic changeability is concerned, however, our conclusions need not necessarily be modified. All that we can now do is to present the problem and to attempt to explain it by a theory consistent with the facts. With our present scanty knowledge of the exact effects of varying conditions of temperature, pressure, humidity and the like upon man's vital processes, it would be rash to say that the difference between the Yucatan of the past and that of the present is due to climatic causes more than to anything else. This much, however, can be safely said: if the shifting of zones has taken place in any such way as we have inferred, the peculiar contrast between the wonderfully progressive people who once dwelt in Yucatan and the indolent present inhabitants is much less inexplicable than is now the case.